APPENDIX G

GENERAL OBSERVATIONS OF URANIUM MINE SITES IN COLORADO, NEW MEXICO, TEXAS, AND WYOMING

G.1. General observations on inactive uranium mine sites in Colorado, New Mexico, Texas, and Wyoming

"Walk through" surveys were conducted at selected inactive uranium mines in Colorado, New Mexico, Texas, and Wyoming. The primary purpose of the "walk through" surveys was to note and describe the general environmental conditions of the mines. Limited gamma radiation rate measurements were made at each site and estimates were made of the volume and area of the mine wastes. In addition, each waste area was observed for indications of wind and water erosion and to see if the mine entry and vents were open to the atmosphere.

G.1.1 Colorado

The surveys were conducted at mining areas near Uravan and Boulder, Colorado. Each area is listed, and the survey results at each mine are discussed.

G.1.1.1 Uravan Area

The Uravan area lies within the Uravan Mineral Belt, which is situated on the Utah-Colorado border, encompassing parts of Mesa, Montrose, and San Miguel Counties in Colorado and Grand and San Juan Counties in Utah. Uranium has been mined in the belt from the Salt Wash Member of the Morrison Formation since 1900. About 150 mines were being worked in the belt in 1978. Three companies have announced their intention to build mills in the belt area (Wh78). Ore deposits are found mainly in sandstone lenses which are up to 1,600 m wide and average about 15 m thick. The ore deposits range in size from a few MT in the form of a fossil log to many thousands of MT. The ore deposits generally range in thickness from a few centimeters to 7.6 m. Irregularly shaped, they can be found almost anywhere within the sandstone lenses. One study of the Salt Wash deposits indicated that 70 percent of the deposits contained less than 2,700 MT of ore each (Wh78).

Since the ore bodies occur as rolls, pods, or tabular masses, their size precludes the use of a prearranged and uniform stoping system. Mining practices were to simply follow the ore and leave open stopes behind. Consequently, a large number of relatively small mines have been operated in this mineral belt. One mill processed ore from 200 mines which have produced ore ranging from 91 to 910,000 MT.

A substantial fraction of the inactive mines are located in or near the Uravan Mineral Belt and are listed by State and county. A total of 1860 inactive uranium mines, or about 57 percent of all inactive uranium mines in the entire United States, are located in or near the Uravan Mineral Belt.

State	County	Inactive Mines	
		Surface	Underground
Colorado	Mesa	77	109
Colorado	Montrose	76	404
Colorado	San Miguel	70	269
Utah	Emery	60	126
Utah	Grand	69	95
Utah	San Juan	140	365
	Total	492	1368

G.1.1.1.1 Mine 1

This mine had a vertical shaft which was barricaded to prevent livestock from falling into it; however, it remains open to the atmosphere. About 13,800 cubic meters of mine wastes were dumped on a downslope area adjacent to the shaft presently covering an area of about 0.1 hectare (Fig. G.1). There was evidence of wind and water erosion of the wastes. Exposure rates, measured 0.914 m above the wastes, ranged from 140-170 μR/hr with several spots reaching 250 μR/hr. Several small adjacent waste piles had exposure rates of 110 μR/hr. No springs or standing water were observed near the wastes.

G.1.1.1.2 Mine 2

This rim mine (Fig. G.2) faces the San Miguel river valley and produced about 1,200 cubic meters of wastes, which were dumped down the canyon wall and presently cover an area of about 0.4 hectare. Exposure rates measured near the dump point were about 200 μR/hr; measurements on the road around the ore bins ranged from 50-150 μR/hr. The mine entry remains open to the atmosphere. There was evidence of wind and water erosion of the mine wastes.

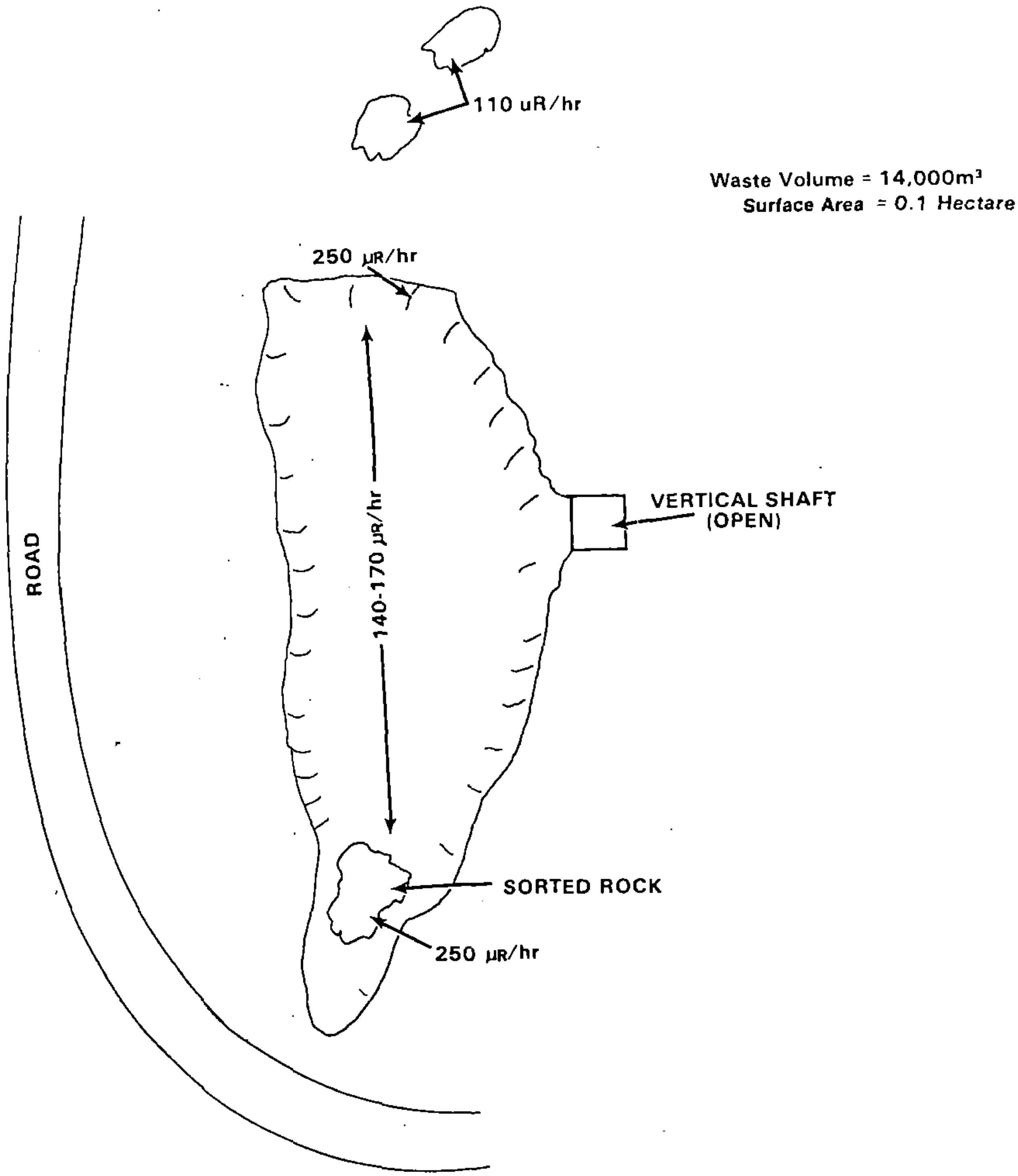


Figure G.1 Plan view of inactive underground uranium mine No. 1, related waste rock piles, and surface gamma exposure rates, Uravan *Mineral* Belt, Colorado

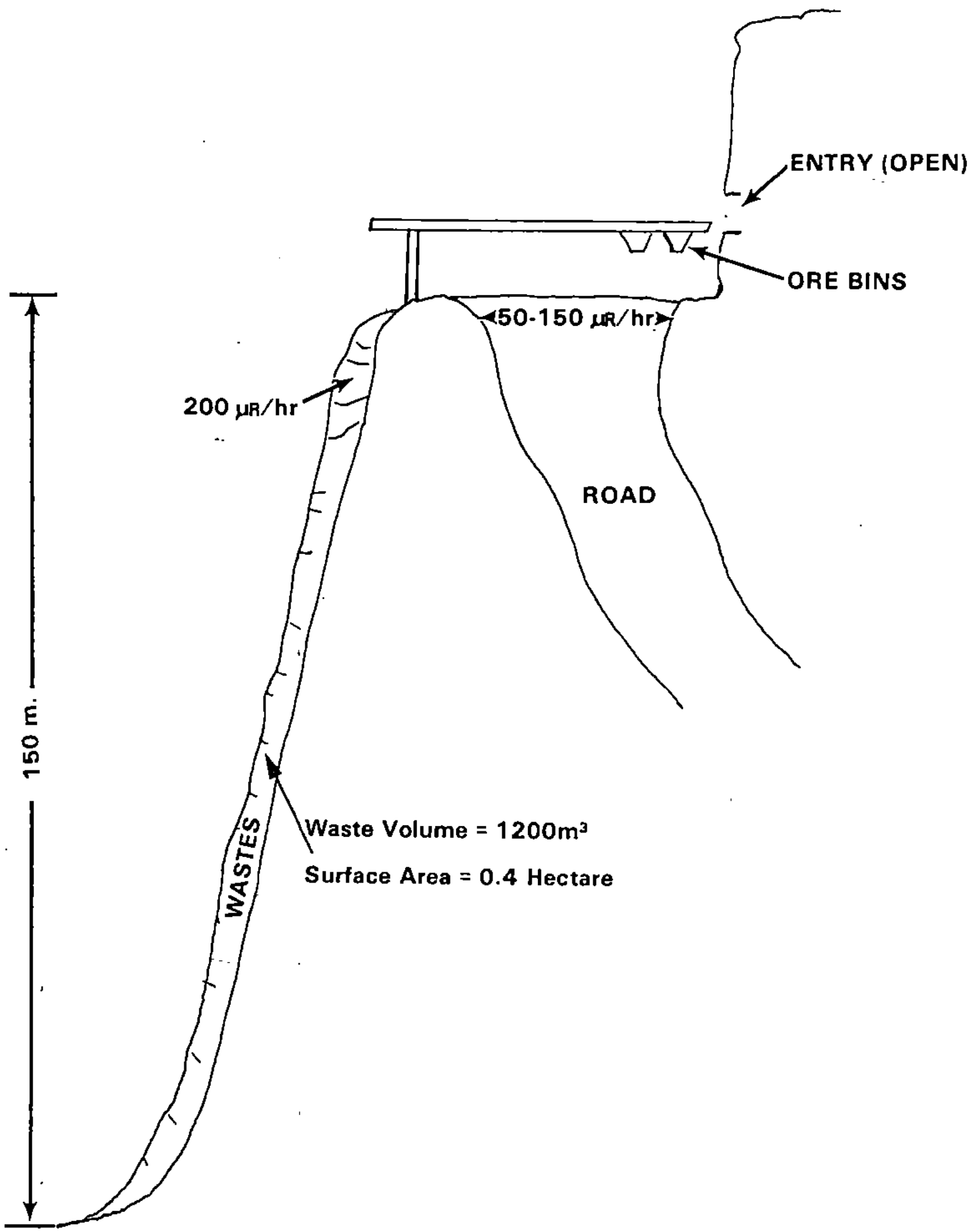


Figure G.2 Sectional view of inactive underground uranium mine No. 2, related waste rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado

G.1.1.1.3 Mine 3

This mine has an incline entry that remains open to the atmosphere. Two waste piles were built up to support ore bins (Fig. G.3). About 38,300 cubic meters of wastes, which have a surface area of about two hectares, are contained in the two piles. Part of the waste piles extend into an adjacent wash and are subject to water erosion. Wind erosion of the wastes was also evident. Gamma exposure rates on the waste piles ranged from 120-150 μR/hr, while areas adjacent to the piles were about 160 μR/hr. The exposure rate on the mine access road was 80 μR/hr.

G.1.1.1.4 Mine 4

This was a rim mine with a portal remaining open. The mine wastes volume was about 6,100 cubic meters covering an area of about 0.4 hectares (Fig. G.4). Wastes have eroded down the slope, through a drain pipe under the highway, and into the San Miguel River. Exposure rates on the access road and under the ore bins were about 70 μR/hr. Wind erosion of the wastes was also evident.

G.1.1.1.5 Mine 5

This mine contained a vertical shaft used for forced ventilation of connecting mines (Fig. G.5). An undetermined amount of low-grade ore had been dumped in small piles covering an area of about 5 hectares and was later removed for milling. The two remaining piles cover about 1.2 hectares and contain about 76,500 m^3 of protore and barren wastes including clean-up materials from the 5 hectare area. Gamma exposure rates over the former waste area ranged from 50-150 μR/hr. Exposure rates over the consolidated piles ranged from 50-220 μR/hr. Wind and water erosion were evident at both the former and present waste storage areas.

G.1.1.1.6 Mine 6

This mine had a vertical shaft used to force ventilate connecting active mines (Fig. G.6). About 45,900 cubic meters of wastes were dumped on a downslope adjacent to the mine shaft and now cover about 0.4 hectare of ground. Gamma exposure rates measured over the waste pile ranged from 180-220 μR/hr. Runoff and wind erosion of the wastes were evident. Some of the runoff appeared to have entered a nearby stock pond.

Waste Volume = 38,000m³

Surface Area = 2 Hectares

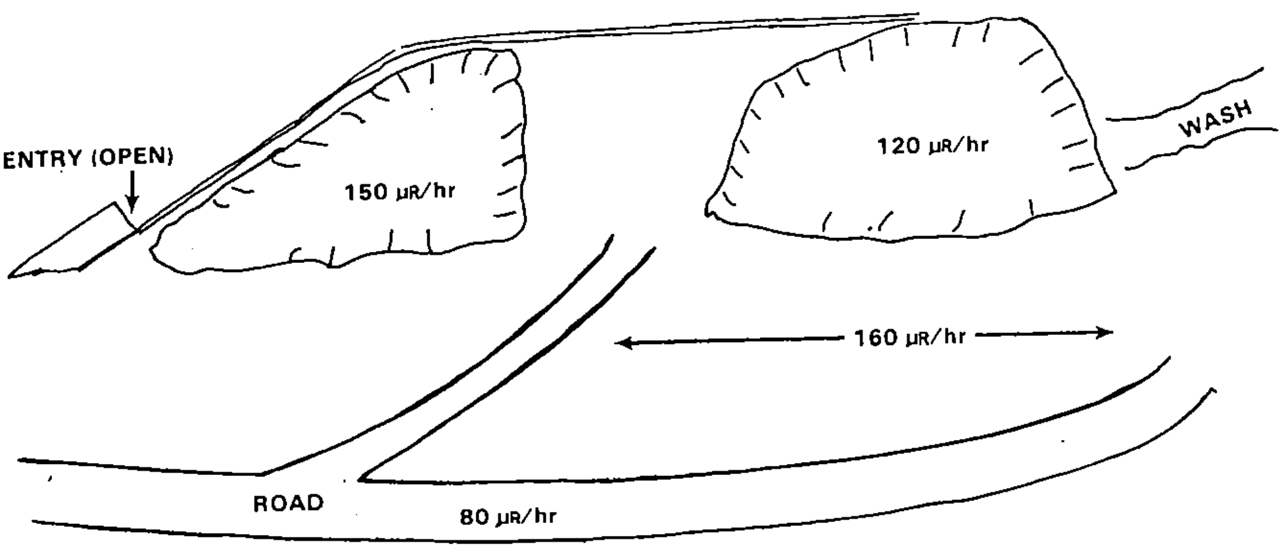


Figure G.3 Plan view of inactive underground uranium mine No. 3, related waste rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado

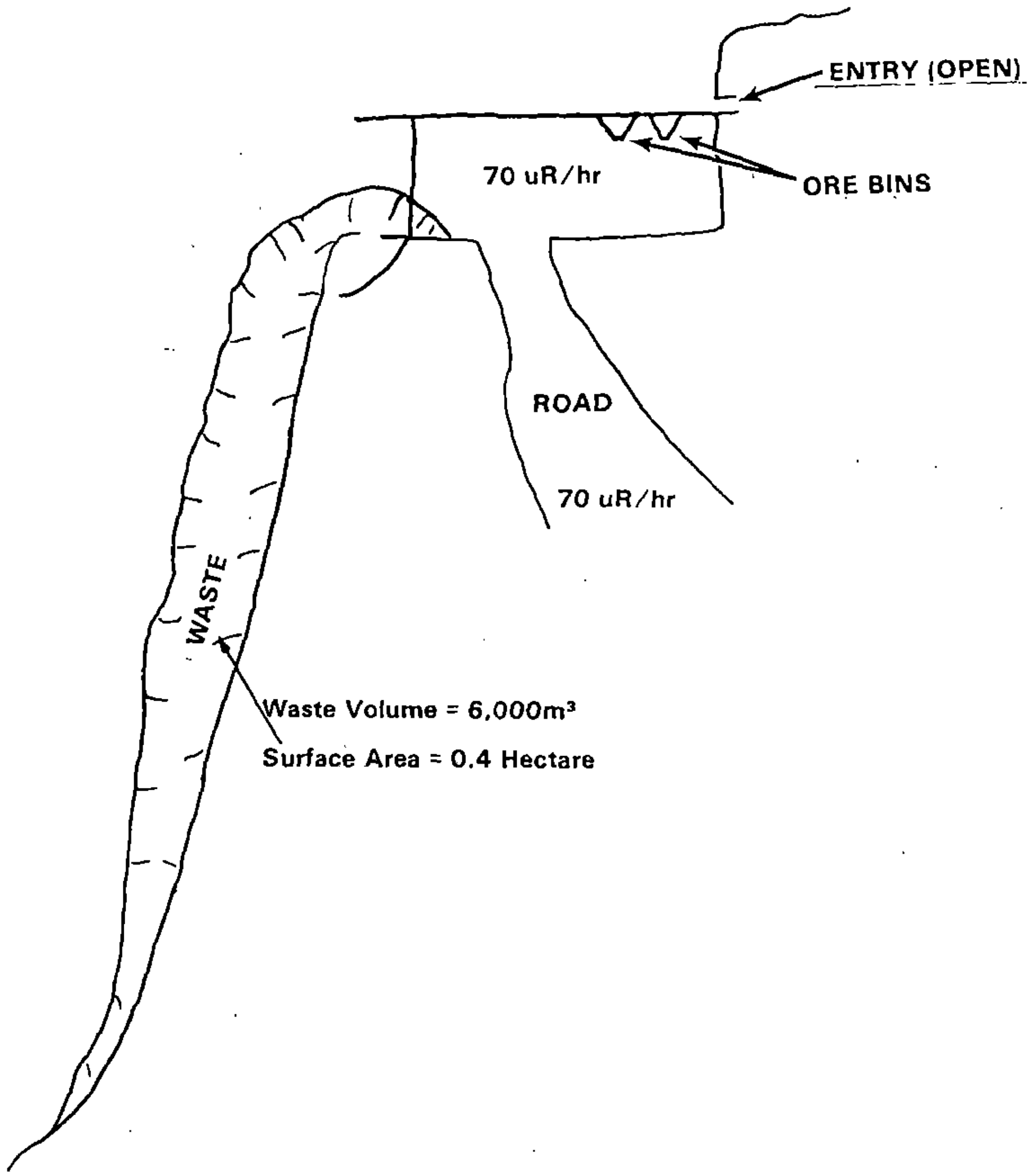


Figure G.4 Sectional view of inactive underground uranium mine No. 4, related waste rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado

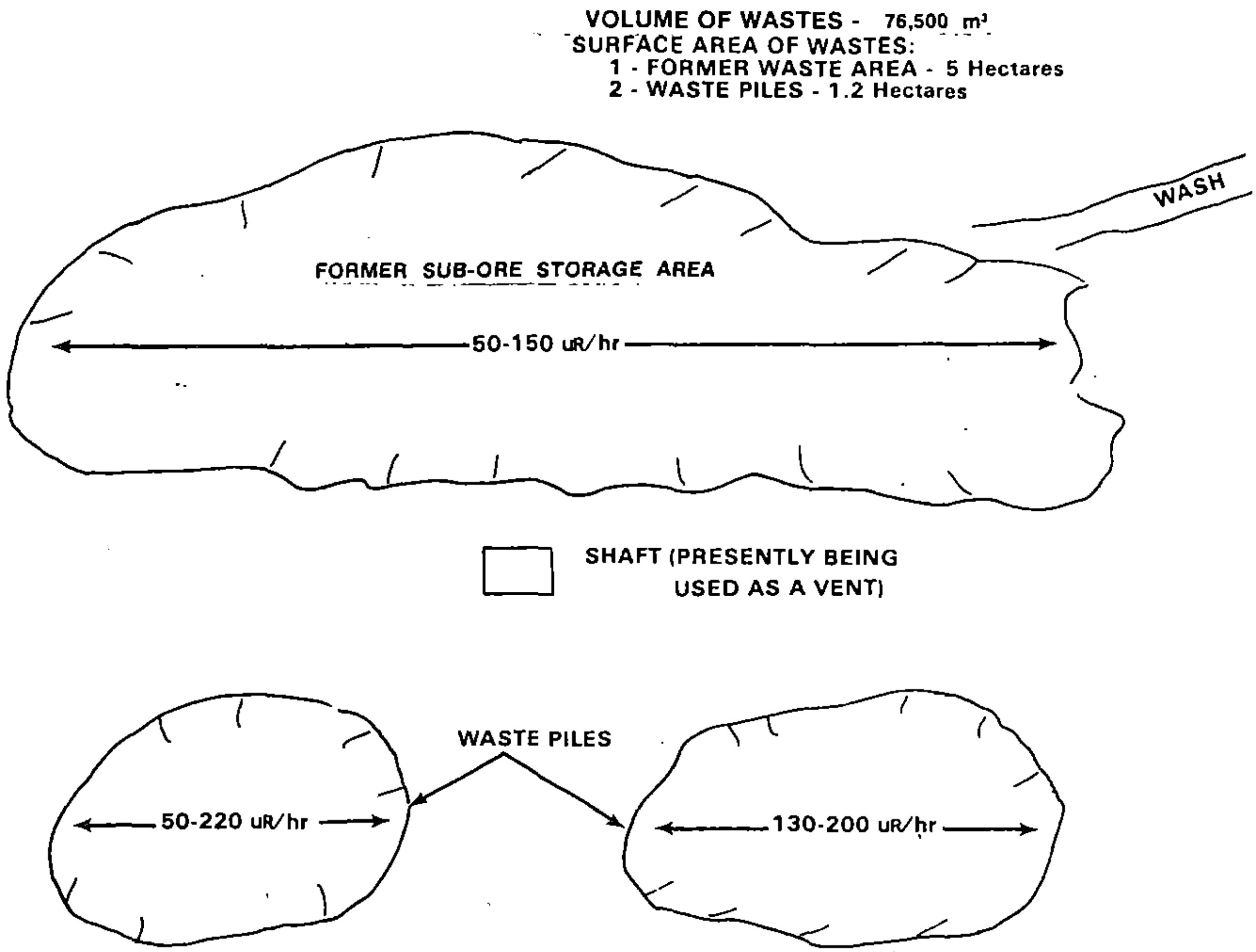


Figure G.5 Plan view of inactive underground uranium mine No. 5, related rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado

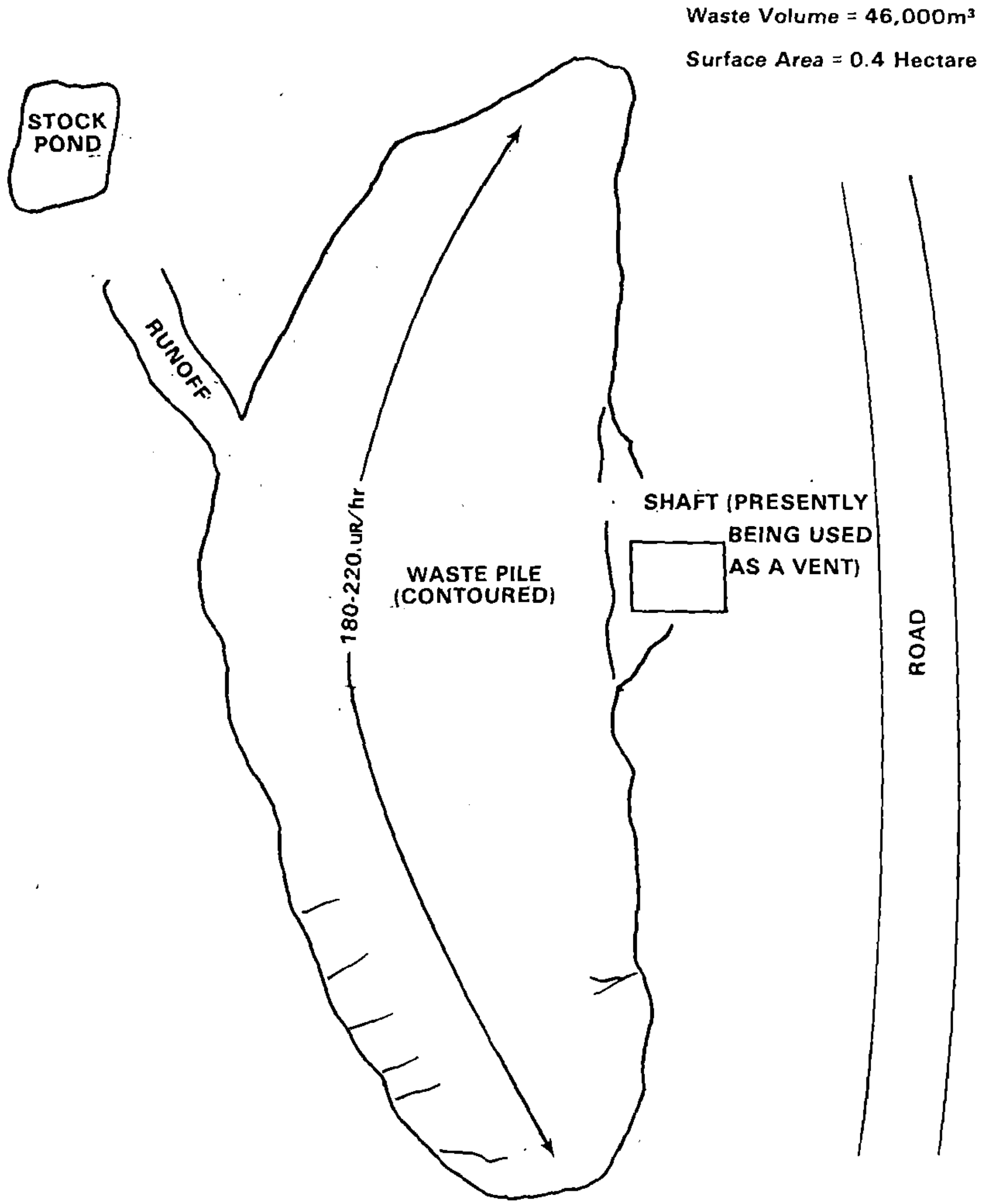


Figure G.6 Plan view of inactive underground uranium mine No. 6, related waste rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado

G.1.1.2 Jamestown Area

Uranium ore bodies in the Central City District area generally tend to be small but high in grade. They are mined in conjunction with precious and base-metal ores, particularly gold mining. Pitchblende, associated with all types of veins and shoots, occurs in small pods or lenses systematically arranged in some veins but erratically distributed in others (Si56). Small quantities of pitchblende ore have been shipped from the Central City District since 1872; however, most of the ore mined before 1917 was used as a source of radium. The fluorite ores of the Jamestown District contain small amounts of base metal sulfides and some uranium ore. The quantity of uranium ore was insufficient to be mined for uranium alone (Bu56). The surveys conducted in the Jamestown, Colorado area were made to evaluate some mining areas where uranium was recovered as a by-product.

G.1.1.2.1 Mine 7

This mine was relatively small and produced high grade ore (Fig. G.7). About 38 cubic meters of wastes remain around the shaft, and gamma exposure rates of 400 μR/hr were measured. Erosion of the wastes into the nearby wash was evident. Wind erosion is probably minimal. The mine shaft remains open but filled with water.

G.1.1.2.2 Mine 8

This mine was principally a fluorspar producer; however, uranium ore was also produced and sold (Fig. G.8). The mine shaft remains open to the atmosphere. Mine wastes, adjacent to the shaft, occupy about 800 m^2, estimated to be about 1,700 cubic meters. Gamma exposure rates on the waste pile ranged from 60-80 μR/hr. Extensive water erosion of the wastes has occurred and has produced exposure rates below the waste piles ranging from 40-100 μR/hr. Wind erosion of the wastes is probably minimal.

G.1.1.2.3 Mine 9

This mine (Fig. G.9) was located adjacent to the highway just south of Jamestown, Colorado. The mine entry has been covered by a landslide. About 460 cubic meters of wastes, an area of about 400 m^2, are present on the site. Exposure rates near the entry were about 100 μR/hr and ranged from 40-60 μR/hr near the highway.

Waste Volume = $38 m^3$
Surface Area = 0.04 Hectare

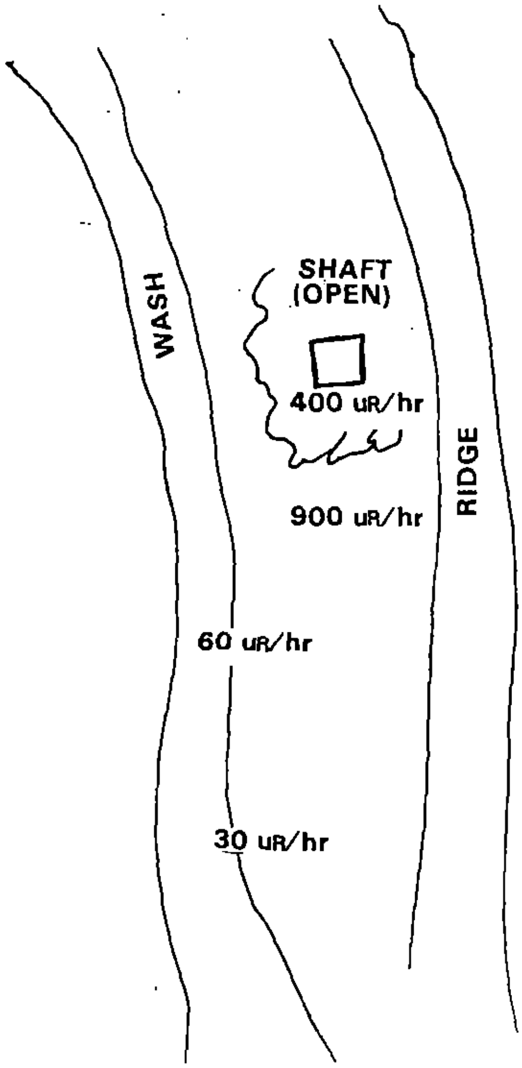


Figure G.7 Plan view of inactive underground uranium mine No. 7, related waste rock piles, and surface gamma exposure rates, Central City District, Colorado

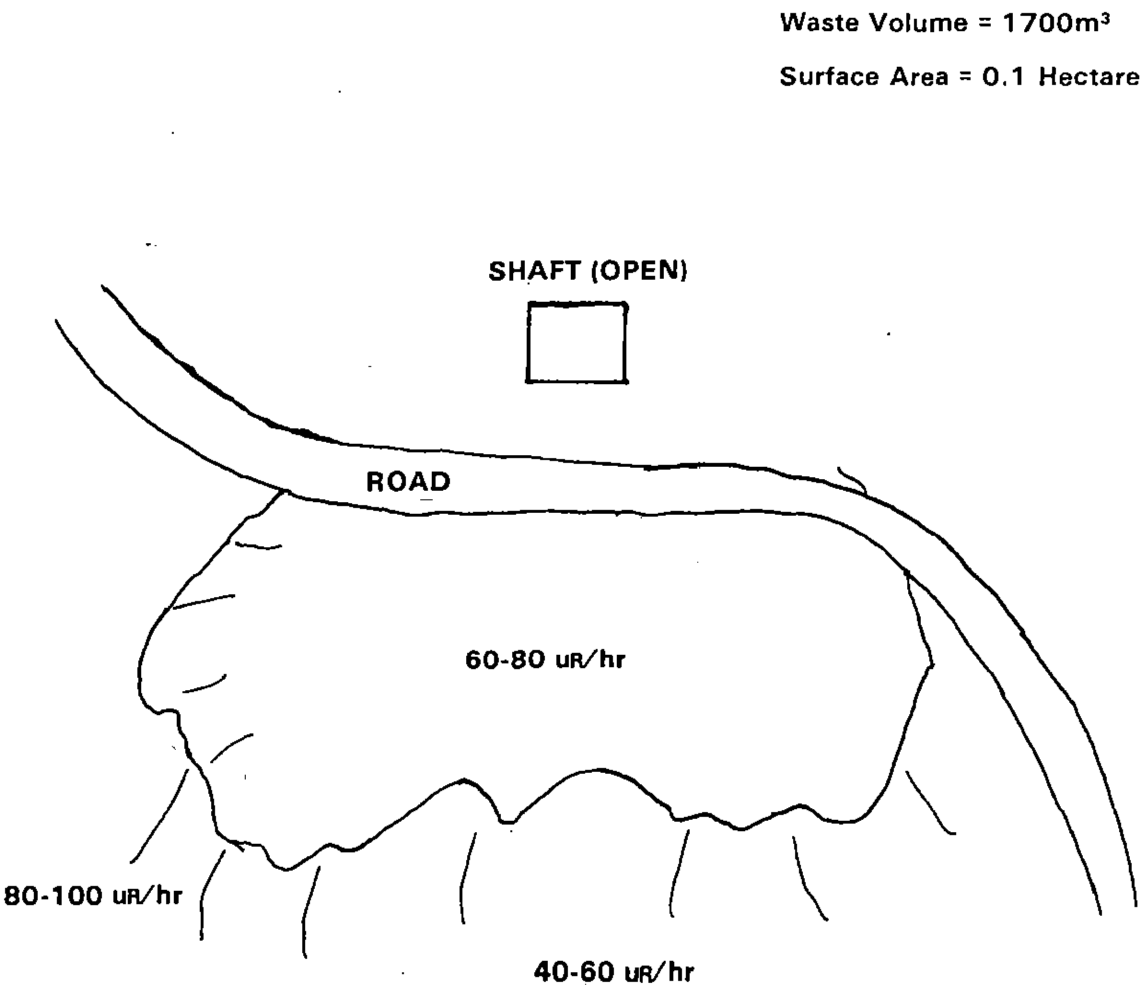


Figure G.8 Plan view of inactive underground uranium mine No. 8, related waste rock piles, and surface gamma exposure rates, Central City District, Colorado

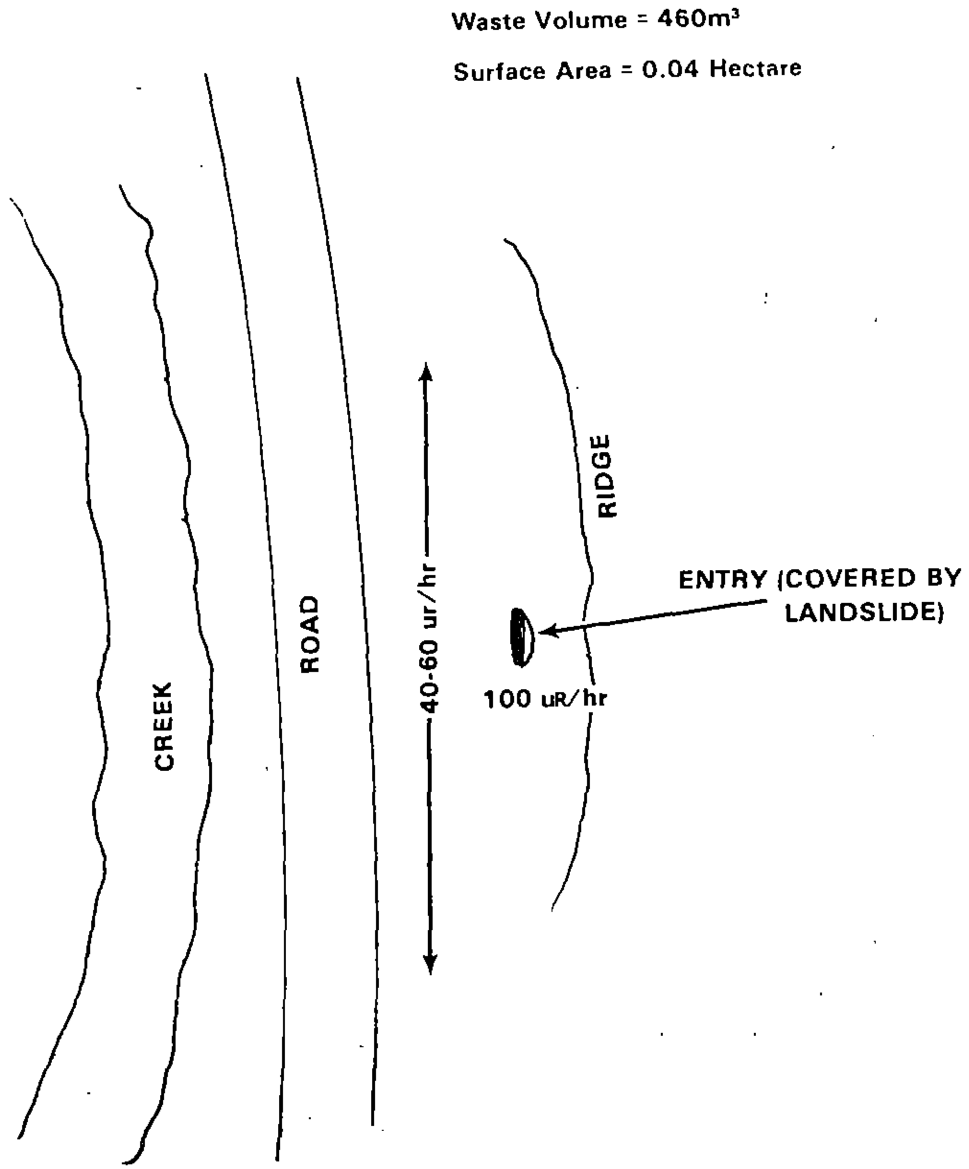


Figure G.9 Plan view of inactive underground fluorspar-uranium mine No. 9, related waste rock piles, and surface gamma exposure rates, near Jamestown, Colorado

G.1.1.2.4 Mine 10

This mine was relatively small and the entry remains open (Fig. G.10). Exposure rates near the entry ranged from 100-600 μR/hr. Exposure rates on the mine access road were about 70 μR/hr. Piles containing mine wastes occupy about 0.1 hectare with a volume of 150 cubic meters. Water and wind erosion of the wastes was evident.

G.1.1.3 Summary

Those mines surveyed in the Uravan area are probably typical of the many inactive uranium mines in that area. Most of the mines are underground and relatively small. Wind and water erosion of the waste piles was evident at all of the mines having entryways open, except where noted. Information derived from these mine surveys is presented in Table G.1 below. Some typical mine waste piles are shown in Fig. G.11. Subsequent photographs depict a typical rim mine (Fig. G.12), an accumulation of wastes on a ledge from a typical rim mine (Fig. G.13), and a mine waste dump from a rim mine (Fig. G.14).

Table G.1 Uravan and Jamestown areas

Mine	Cubic Meters of Wastes	Surface Area of Wastes (Hectares)
	Uravan area	
1	13,800	0.1
2	1,200	0.4
3	38,000	2.0
4	6,100	0.4
5	76,500	1.2
6	46,000	0.4
	Jamestown area	
7	38	0.04
8	1,700	0.08
9	460	0.04
10	150	0.1

Waste Volume = 150m³

Surface Area = 0.1 Hectare

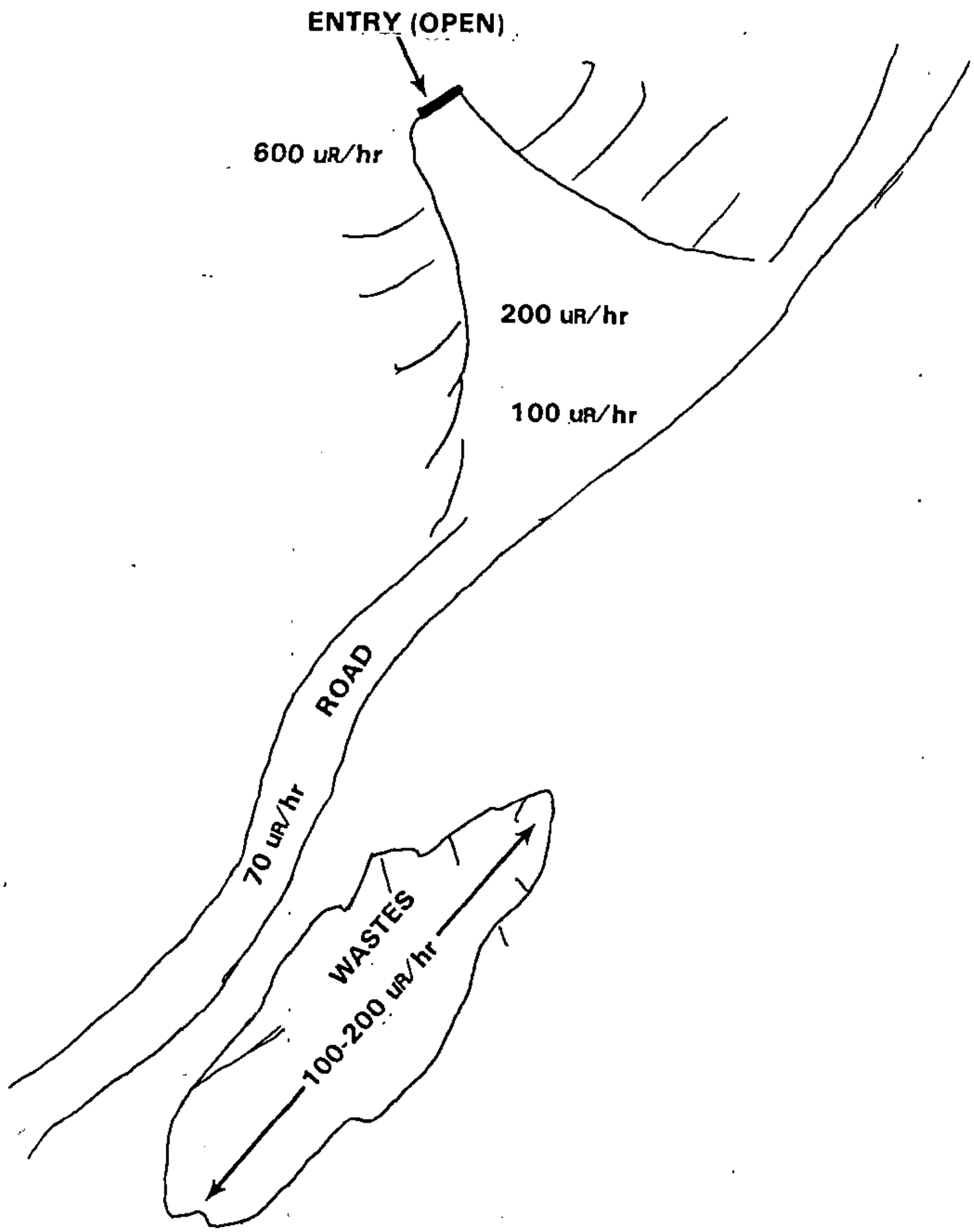


Figure G.10 Plan view of inactive underground uranium mine No. 10, related waste rock piles, and surface gamma exposure rates, Central City District, Colorado

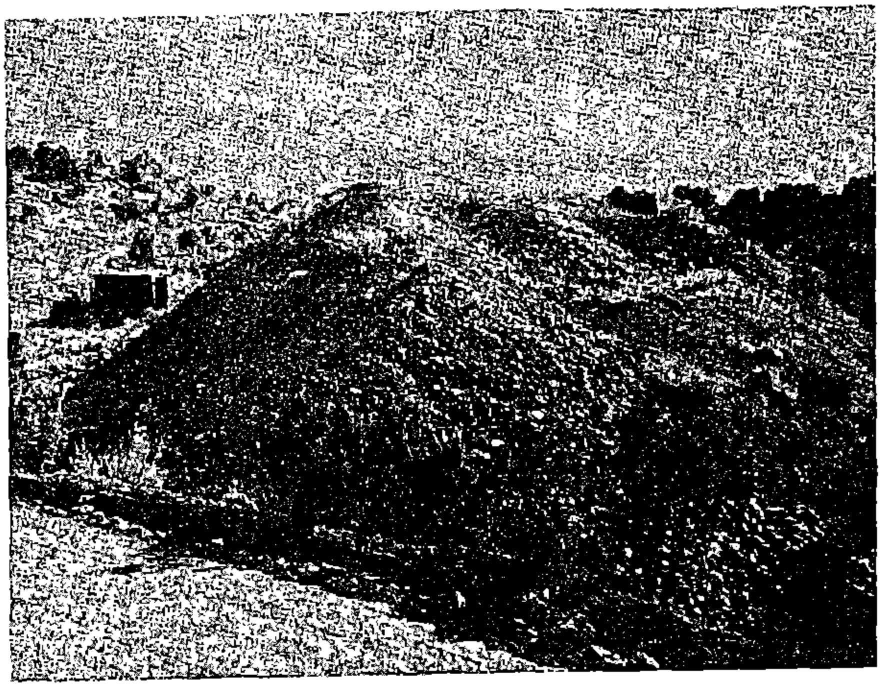


Figure G.11 Typical mine waste pile associated with a small- to medium-sized inactive underground uranium mine in the Uravan Mineral Belt, Colorado

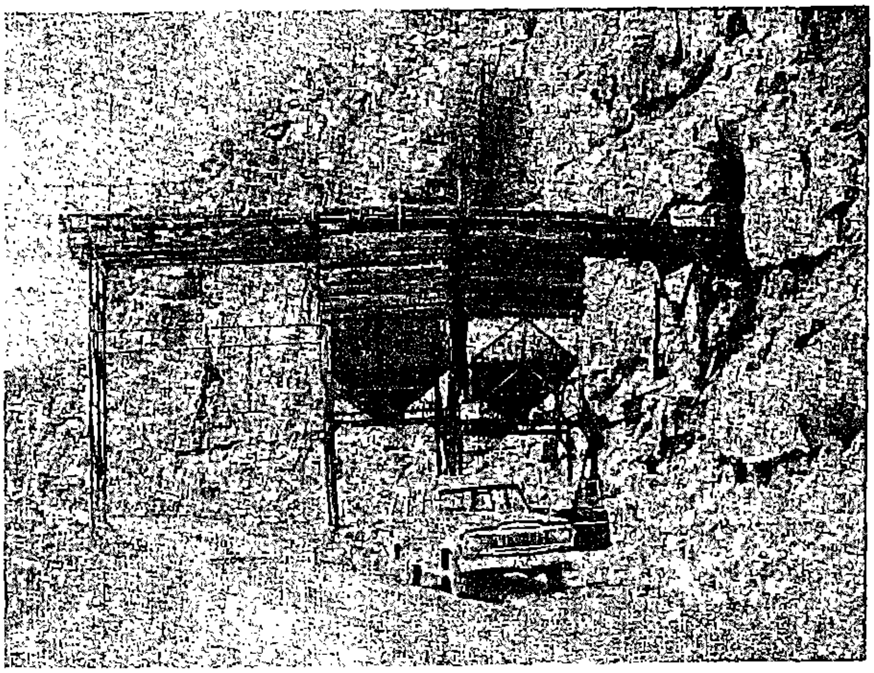


Figure G.12 Side view of a typical underground uranium mine located on the rim of a sandstone mesa in the Uravan Mineral Belt, Colorado

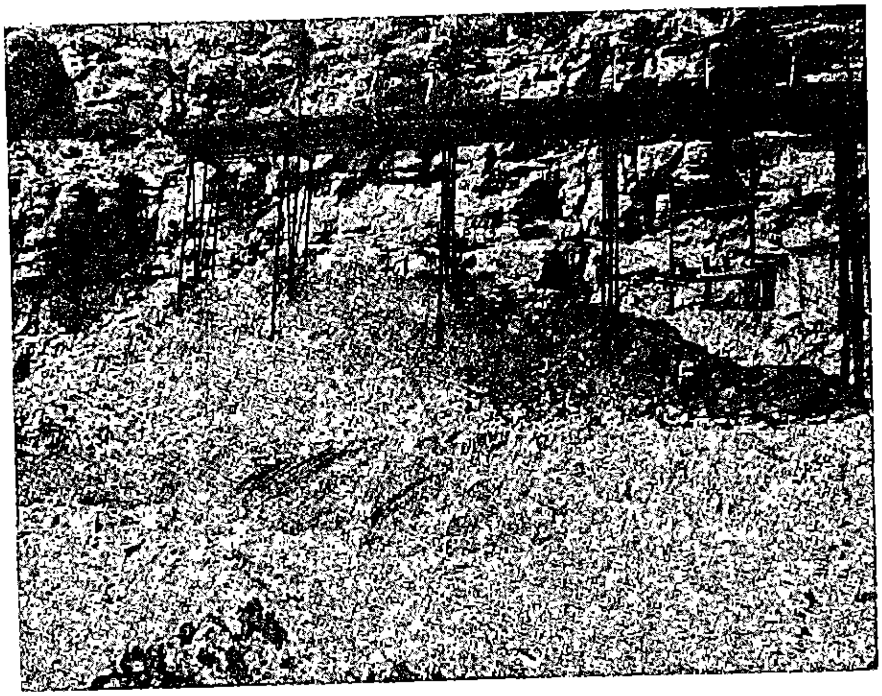


Figure G.13 Mine waste accumulations near the portal of a typical underground rim-type uranium mine in western Colorado

Figure G.14 Mine waste dump associated with a typical rim-type underground uranium mine in western Colorado

Ore-hauling losses have occurred along the mine access and public roads. In addition, mine wastes have been used for road ballast. The ore losses and mine wastes used for road construction probably became airborne with some of the large quantities of dust produced by ore-hauling equipment. The lands in the mining areas generally are used for grazing. Some enhanced uptake of radioactive materials and trace metals by cattle may be occurring. Exploratory drilling is abundant throughout the survey area. Little or no reclamation of abandoned drill sites was observed.

Mines 7 through 10 were surveyed near Jamestown, Colorado. This type of mine was prevalent in this area. Although uranium was not principally produced by many of the mines, the mine wastes generally contain radioactivity. Figure G.15 shows wastes at one such mine entering a stream. Mine wastes producing exposure rates of 40-100 μR/hr in that area were used as a fill for the Jamestown Park (210 acres). Evidence indicates that some dwellings were built on or near the mine wastes. Surface and groundwater contamination from the mining activities is possible.

G.1.2 New Mexico

Uranium mining operations are continuing to expand production throughout the Grants Mineral Belt region of New Mexico. Underground mining is predominant in the Ambrosia Lake, Churchrock, and Crownpoint areas. Surface mining operations are also expanding at the Jackpile and St. Anthony mines near Paguate/Laguna. However, the majority of inactive uranium mines are located in the area around Grants; therefore, this area was selected for the reconnaissance and field study surveys in New Mexico.

G.1.2.1 Inactive Surface Mines

Two inactive surface mining areas were observed - the Poison Canyon and Zia strip mining areas. Both inactive sites appear to have been more of a shallow strip mining operation compared to the extensive and deeper open pit operations currently underway at the Jackpile and St. Anthony mines. Shallow ore pockets were removed at the Poison Canyon and Zia areas, leaving relatively small pits and waste piles scattered over several hectares. Field studies were completed at several of the Poison Canyon open pits; the radiological data obtained from these surveys are summarized below.

Figure G.15 Movement of fluorspar-uranium mine wastes from a tailings pile into a stream in the Jamestown area of Colorado

G.1.2.2 Inactive Underground Mines

Six underground mines (vertical shaft and incline mining) were observed on Mesa Montanosa: Beacon Hill, Davenport, Dog, Flea, Mesa Top, and Malpais. Several of these mines (e.g., Mesa Top and Malpais mines) were interconnected during their active mining periods. A few of these inactive mines are being used today as fresh air intake points for active mining operations in the area (e.g., mine vents of the inactive Gossett mine are being used in the ventilation system of the active Poison Canyon Mine).

Five underground mines were visited in the Poison Canyon area - Barbara Jane 1 and 3, Westvaco, Santa Fe, and Flat Top mines. Also visited were the Marcus, San Mateo, Anaconda F-33, Hogan, Dakota, and Dysart No. 1 mines. Table G.2 summarizes the reconnaissance and field study survey results.

G.1.2.3 Summary

In summary, the open pit (strip mining) areas of New Mexico have not been restored and numerous shallow open pits or trenches remain with their waste piles undergoing rainwater runoff and windblown contamination of surrounding areas. Most of the inactive underground mine sites have had the head frame and buildings removed and the portals sealed by timber or steel plates to prevent entry, but openings do allow radon exhaust via natural ventilation of the mine. Most mine sites have waste piles which are undergoing rainwater runoff and windblown contamination of surrounding areas. Most of the cased mine vents are not capped to prevent radon exhausting. No mine water drainage was apparent at any of the sites, and most of the mines appear to have collapsed or are flooded.

G.1.3 Texas

Compared to some other western states, the uranium production of south Texas is relatively insignificant, comprising 5 percent of the current United States annual total. However, the relative impact of the mining operations is of interest herein for several reasons: 1) geographic concentration of the actual mine operations, 2) close proximity of the mines to the general population, 3) effect of the high precipitation of the region on the relatively abundant toxic trace elements in the uranium ore and overburden, and 4) minimal land reclamation of some of the older mines which produced high grade ore. The location of uranium ore deposits in south Texas can be readily estimated from the mine locations shown in Fig. 2.4. The deposits

Table G.2 Inactive uranium mine sites surveyed in New Mexico

Mine	Township and Range	Description
Anaconda F-33	T12N R9W Sect. 33 and 34	Two portals sealed by steel doors, large waste piles, no water, runoff apparent, no vents found.
Barbara Jane 1	T13N R19W Sect. 30	No head frame, portal covered by steel plate, but open. Shaft appears to be open, no water, relatively small waste pile, runoff from waste pile, three open mine vents and one capped. Surveys completed at this site.
Barbara Jane 3	T13N R19W Sect. 30	Head frame remains, portal covered by steel plate but openings. Shaft appears to have collapsed. Water drainage from active mine flows through area, small waste piles cleaned off to surface. Several (about six) cased mine vents open to surface.
Beacon Hill	T13N R9W Sect. 20	Small head frame, incline shaft is collapsed. Waste piles in area, no water but runoff apparent. No vents found.
Dakota	T13N R10W Sect.4	Two open portals but mine not deep. Some waste piles, no vents found, no water, runoff apparent.
Davenport	T13N R9W Sect. 20	Open incline but roof collapsed about 60 yards into mine. No vents found. Waste piles in area, no water, runoff apparent. Surveys completed at this site.
Dog Mine	T13N R9W Sect.20	Head frame, incline shaft sealed but appears to have collapsed. No vents found. Large water drainage ditch, large waste piles, runoff apparent.
Dysart 1	T14N R10W Sect. 11	Head frame and buildings, open vents but used in nearby active mine system, waste piles, no water, no runoff.

Table G.2 (continued)

Mine	Township and Range	Description
Flat Top	T13N R9W Sect. 30	No head frame, timber and concrete slab over shaft. No water, waste pile cleaned to surface. No runoff. Several open mine vents found nearby.
Flea Mine	T13N R9W Sect. 20	No head frame, portal sealed with timber. No vents. No water but runoff apparent. Large waste piles.
Hogan	T13N R9W Sect. 14	No head frame, concrete pad covers shaft. No vents found, no water. Waste cleaned to surface, no runoff.
Malpais	T13N R9W Sect. 20	Mine shaft not found but believed to be covered by waste piles. No water but runoff apparent.
Marquez	T13N R9W Sect. 23	Building, portal sealed with timber, several open vents. San Mateo Creek flows through site. Waste piles and water runoff.
Mesa Top	T13N R9W Sect. 20	No head frame, shaft sealed with timber but open, large waste piles. Several open mine vents in area. No water runoff apparent. Surveys completed at this site.
Poison Canyon Strip Mines	T13N R10W Sects. 25, 26 and 139	Open pit or strip mining areas. No shafts or buildings, extensive waste piles and numerous pits, no vents. One abandoned water well, rain water in one pit. Runoff apparent, creek flows between several waste piles in Section 25. Surveys completed at this site.
San Mateo	T13N R8W Sect. 30	No head frame, shaft area collapsed. Large waste piles. Heap leach pile, mine water drainage areas. No water, extensive runoff. One open vent found. Surveys completed at this site.

Table G.2 (continued)

Mine	Township and Range	Description
Santa Fe	T13N R9W Sect. 24	Head frame and building, waste cleaned to surface. No water, no runoff, no vents found.
Westvaco	T13N R10W Sect. 25	No head frame, portal caved in to form hole, no vents found. Small waste pile, no water, runoff apparent.
Zia Strip Mines	T12N R9W Sect. 15	Shallow strip mining areas, no shafts or buildings. Waste piles, no water, no runoff apparent, no vents.

are in tuffaceous, zeolitic sandstone and mudstone beds that strike north eastward and dip gently southeastward (Ea75). Uranium is produced from a three-county area comprised of Karnes, Live Oak, and Duval counties. In each area the host rock is different and ranges in age from Eocene to Pliocene. The Catahoula Tuff is believed by many authors to be the principal source rock for uranium and other elements in the deposits.

Uranium ores currently mined in south Texas are generally of very low grade, the average being about 0.06 percent U_3O_8. In the recent past many operations, now inactive, were mining ore of the range 0.20-0.25 percent U_3O_8. The ore zone thickness, although variable, is seldom more than 3.05 m. The usual mining method is by open pit, however, in situ leaching is becoming commonplace and useful under certain conditions. Mine size and geometry are variable, depending on the period of mining activity, the depth of the ore zone, and the proximity (vertically and laterally) of other ore bodies. Many of the mines have a linear trend, paralleling the mineralized roll front. A typical open pit mine would be 30-100 m deep and cover approximately 250,000 m^2. Currently, a stripping ratio of 35:1 is followed in this area. Any groundwater encountered is diverted to sumps and, from there, pumped to holding ponds.

The reclamation of the pit areas involves contouring the land surface such that all drainage is internal to an on-site holding pond. Topsoil cover is spread about evenly and then seeded with various grasses. It is uneconomical to backfill all of the overburden into the pits and, consequently, some pit remnants consisting of steep walls, etc. are usually left. Generally, reduced agricultural and grazing productivity can be expected in the immediate area of the pit and overburden piles, particularly in the case of older mines.

In situ leaching is common when the depth, size, water content, etc. of the ore body prevents economical open pit mining. It is carefully controlled by the State, especially with respect to monitoring requirements. With cessation of leaching it should be noted that local baseline water quality of the mined aquifer is never fully attained. Potential problem areas are locally increased mobility of trace metals and elevated ammonia levels in the leached ore zone. Tailings from in situ leaching operations can be stored on site or transferred to mill tailings piles.

A compilation of both active and inactive mines by location (county) and type of operation is presented in Table G.3 and Fig. 2.4, both of which are based on State data (Co78).

Table G.3 Status and location of uranium mines in Texas

County	Open Pit[a]			In Situ Leaching[a]			Total
	A	I	P	A	I	P	
Karnes	8	35	9				52
Karnes-Gonzales	2						2
Karnes-Atascosa	1						1
Gonzales	1						1
Atascosa		1					1
Bee				1			1
Live Oak	6	8		6			20
Duval	1			2		5	8
Webb-Duval				1			1
Webb				1			1
Total	19	44	9	11	0	5	88

[a] A = active; I = inactive; P = planned.

G.1.3.1 Field Surveys

On May 24-30, 1979, active and inactive open pit uranium mines in Karnes County, Texas were visited in the company of Texas Health Department radiation specialists. The survey included mine wastes and pits in varying stages--active-mining underway, inactive-being reclaimed, inactive-reclaimed, and inactive-abandoned without reclamation. A gamma survey was conducted at one open pit mine that had just been regraded and covered with topsoil but not yet reseeded. The field survey results were supplemented with extensive gamma survey and environmental monitoring results from the Texas Health Department and the Texas Railroad Commission.

Uranium mining in Texas involves considerable and successive description of the land surface as ore bodies are first uncovered and then removed. Tremendous volumes of topsoil, overburden, and water must be relocated a number of times in the course of mining. Dewatering has reached the stage where off-site release is becoming necessary. In the past, mine waters were rarely discharged but were stored in temporary basins on site. Occasionally, mine water was pumped to stock ponds to augment other supplies, typically derived from rainfall runoff. Water quality had to meet accepted standards for stock use.

Figures G.16 and G.17 are of a typical large open pit mine in Texas as of 1972 and 1978. Note the extensive changes in the landscape as unmined land is stripped, mined, and then reclaimed. Much of the overburden is left adjacent to the mines, and standing water remains in most pits. The water originates as groundwater seepage and overland flow from precipitation. The Galen mine, in the right foreground, was abandoned without stabilization about 10 years ago. Natural vegetation is very thin owing to the lack of topsoil and probable toxic effects of trace elements in the wastes. The pile is deeply eroded in places as was shown previously in Figs. 6.10 and 6.11.

Current Texas requirements for stabilization specify that the gamma radiation dose rate must be no more than 0.5 rem per year. For continuous exposure, this corresponds to 57 μR/hr above background (about 5 μR/hr). Results of 21 mine surveys in Texas (Co77) indicated that gamma-ray exposures in excess of 62 μR/hr were found at 16 of the mines surveyed. Contributing causes are mineralized overburden (15 of 16), ore pads not properly decontaminated (8 of 16), and mineralized rock in the pit (4 of 16).

G.1.3.2 Summary

In summary, uranium mining has caused radiation levels at some abandoned uranium mines to exceed natural background levels. On approximately one-tenth of the mined area of south Texas, exposure rates could exceed 60 μR/hr (the equivalent of 0.5 rem per year for continuous exposure). Although no one is believed to be receiving an exposure in excess of 0.5 rem per year now, the area being mined is increasing, and so is the State's population; hence, the potential for increased population exposures is becoming greater. Individuals occupying a dwelling built on abandoned mine

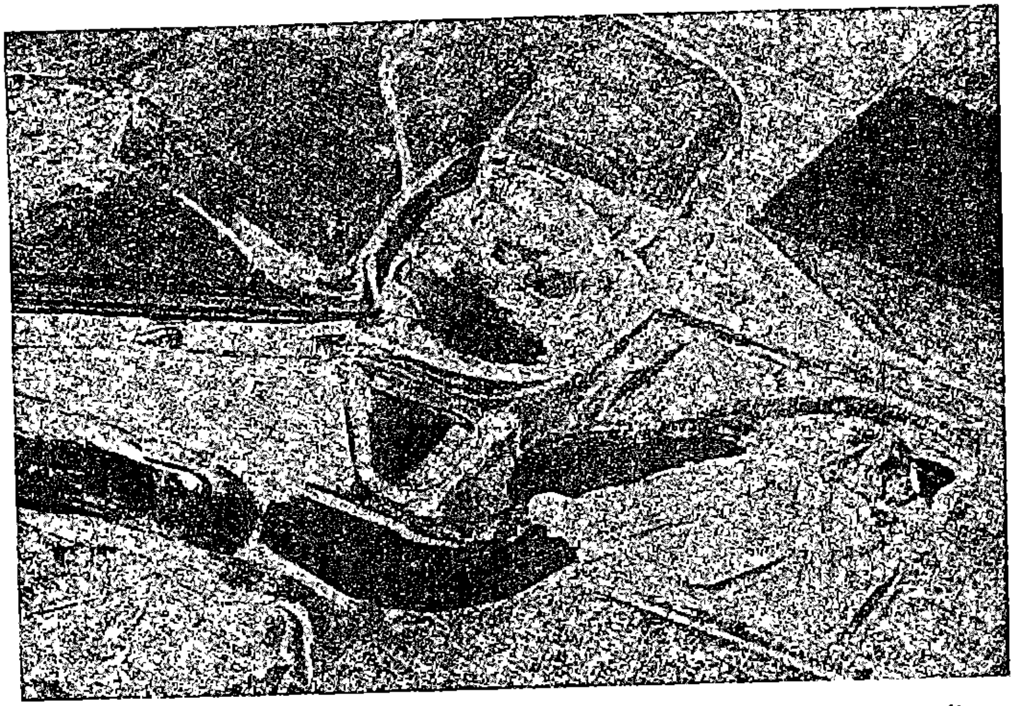


Figure G.16 1972 aerial photograph of the Galen and Pawelek open pit mines, Karnes County, Texas

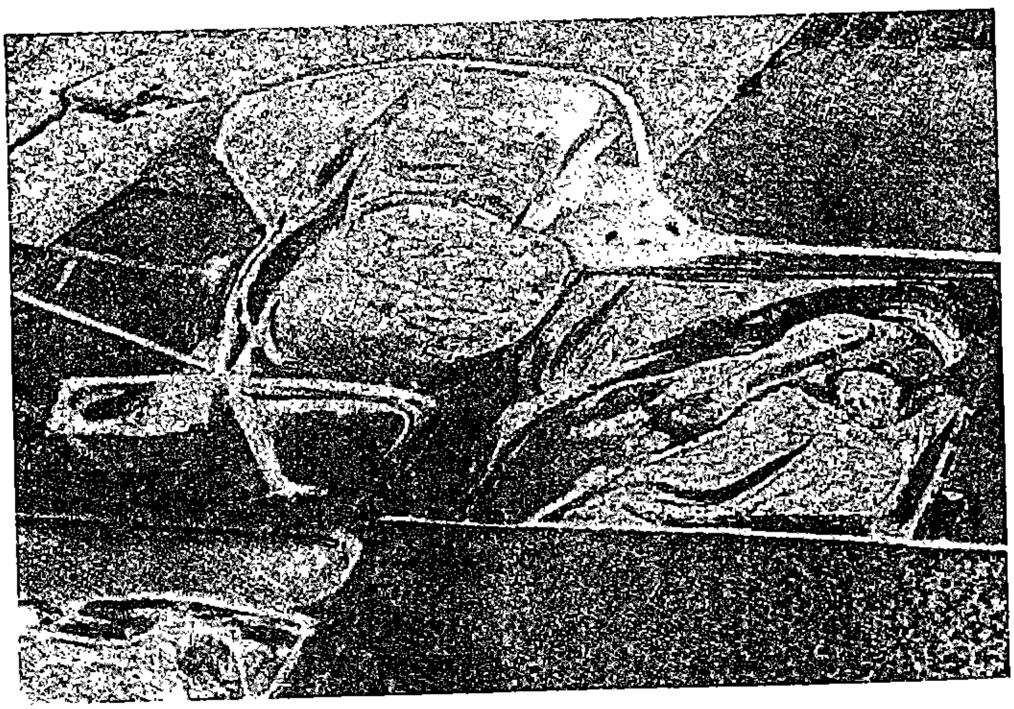


Figure G.17 1978 aerial photograph of the Galen and Pawelek open pit mines, Karnes County, Texas areas could receive excessive lung exposures from radon and its progeny, as well as gamma ray exposures exceeding 0.5 rem per year.

Reclamation by the mining company can reduce radiation levels on mines. One of the most effective methods is to fill in the pit area with the remaining ore, sub-ore, and overburden material and then cover this area with natural dirt or rock of low radioactivity content.

G.1.4 Wyoming

The second largest producer of uranium in the United States is Wyoming. With higher uranium prices, the mining of many low-grade ore deposits would become economical, classifying Wyoming as the largest uranium reserve in the United States. Currently there are many new and expanded operations being planned. Both surface and underground mining methods are used; however, in situ leaching is also underway. Generally, the ore host rocks are arkosic sandstones and conglomerates. Currently, unoxidized ores are being mined, whereas, in the past, shallow oxidized ore bodies were worked. As a result, newer mines are discharging considerably more water to formerly ephemeral streams and, in one case, to a dry lake bed. Within Wyoming, there are 14 major uranium districts, 4 of which are currently producing. These four districts, which are detailed below, exemplify the overall geology of Wyoming uranium occurrences.

G.1.4.1 Highland Flats - Box Creek District

Currently, the largest producing area is the Highland Flats - Box Creek district, located in central Converse County. Host rocks for this deposit are arkosic sandstones of fluvial origin lying within the Fort Union Formation. The ore occurs in roll-type, tabular, and dish-shaped deposits. The largest and most significant of these are the roll-type deposits, varying between 1.5 m and 6.1 m thick. All types are generally associated with each other, occurring from about 46-91 m below the land surface. The ore grade ranges from 0.1 to 0.15 percent U_3O_8. Former mining operations in this area were in the overlying Wasatch Formation and produced ore of approximately 0.22 percent U_3O_8.

G.1.4.2 Crooks Gap District

The second largest producer of uranium, the Crooks Gap district, is located in the Green Mountains of Fremont County. Operations began there in 1954. The host rocks are arkosic sandstones in the Battle Spring Formation. The ore bodies are of tabular, stratiform, and roll-type occurrence modes and are concentrated in narrow zones at the margins of the altered sandstone. Those currently mined are at or below the water table and are unoxidized. Ore grade ranges from 0.18 to 0.23 percent U_3O_8. Formerly, smaller, near-surface ore bodies were mined.

G.1.4.3 Gas Hills District

The Gas Hills district has produced the most uranium in Wyoming and has the largest number of mine and mill operations. Large-scale continuous production has occurred since 1960. It is located in eastern Fremont County. The host rocks are arkosic sandstones in the Wind River Formation. Within this region there are four types of deposits, the roll-type being the most important. These are found at depths of about 30 m to 150 m below the surface and up to 122 m below the water table. The ore zones are 0.3 m to 3.1 m thick, occasionally ranging from 6 m to 10 m thick. The current ore grade is approximately 0.1 to 0.15 percent U_3O_8. Also within the district are small, high-grade residual deposits behind the main solution front deposits.

G.1.4.4 Shirley Basin District

The Shirley Basin district in northwest Carbon County has been actively mined since 1960 and is expected to expand considerably. The host rocks are arkosic sandstones within the Wind River Formation and the deposits are of the roll-type. Found at the leading edge of the tongue of the roll-front, the ore bodies tend to be large, about 15 m wide by 760 m long. Smaller ore bodies are found along the top and bottom of the roll-front. Overall, the ore bodies vary from a few hundred to a few thousand MT, at depths from 45 m to 90 m below the surface. Main ore bodies lie below the groundwater table, sometimes to depths of 90 m. The ore grade ranges from 0.2 to 0.6 percent U_3O_8.

G.1.4.5 Summary

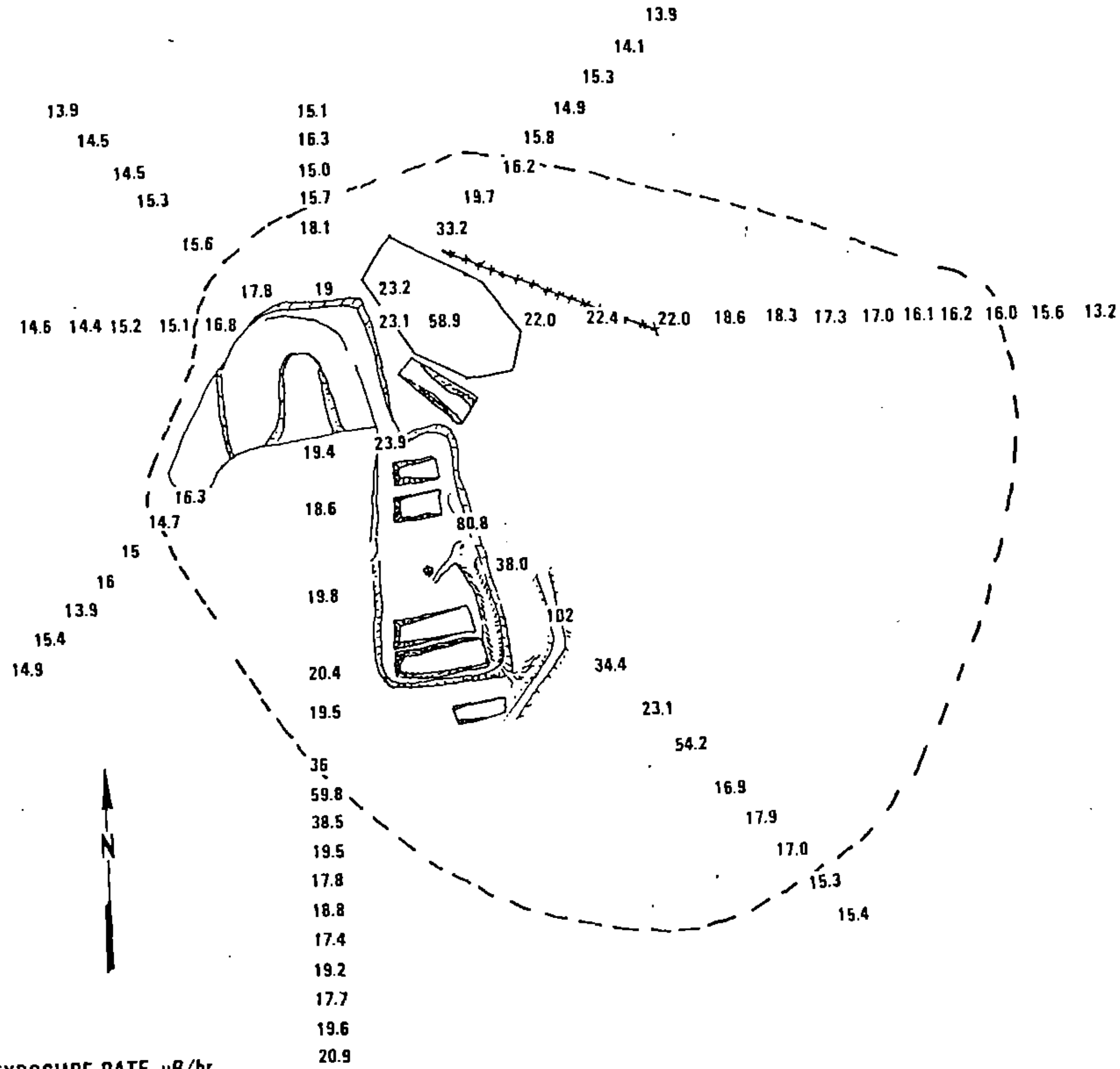
Approximately 90 percent of the ore produced comes from surface mining operations. Overburden thickness ranges from 30.5 m to 137 m below ground surface. Spoils bank accumulation is on the order of 764 x 10^3 m^3/month for an average lifetime of 15 years. This material is stockpiled for later reclamation pursuant to the State Environmental Quality Act of 1973; however, to date, land reclamation has not begun at any surface mine site. It is evident that the mine waste volume from an underground mining operation is much less than that generated by an open pit mine; therefore, it is estimated that about two hectares per portal would be sufficient to dispose of the waste rock.

The majority of the inactive mines are located in the Gas Hills and Shirley Basin mining districts, located in Fremont and Carbon Counties, respectively (Personal communication with UNC staff 1979). There are some inactive but not abandoned mines at every production area. Any increase in the value of U_3O_8 will lead to the reopening of many mines. Therefore, it is difficult to select an inactive mine that would be considered abandoned (mined out).

The Morton Ranch leasehold, described as typical of smaller inactive and perhaps abandoned operations, was the site of the radiological survey. The topographical and climatological parameters of the area are similar in practically any portion of central Wyoming. Precipitation ranges from 30 cm to 36 cm per year, with June being the wettest month, November the driest. The wind blows constantly at variable frequencies up to 129 km/hr (NUREG 0438). The topography is dominated by plains, low-lying hills, and table lands interrupted by stream channelways.

In 1973, an inactive pit, 1601, was very briefly mined to determine the metallurgical qualities of the underlying ore. A pit 110 m x 238 m x 12.2 m deep remains. Adjacent to the pit, piles containing 237,000 m^3 [73,000 m^3 of ore and 164,000 m^3 of spoil (sub-ore)] of spoil material occupies less than 2.5 hectares.

Results of the gamma survey performed along radials originating from the center of the pit appear in Fig. G.18. The near-surface ore body complicated field results from the survey; therefore, soil samples were taken at every 366 m to determine the presence of wind-blown material or surface ore outcropping. Additional soil samples, 75 cm profiles, were taken at erosional occurrences and in drainages.



GROSS GAMMA EXPOSURE RATE uR/hr

Figure G.18 Results of gamma exposure rate survey at the 1601 pit and environs, Morton Ranch uranium mine, Converse County, Wyoming

G.2 Aqueous Transport of Mining Wastes in New Mexico and Wyoming

G.2.1 Description of Field Studies

Field studies were conducted to investigate the transport of trace elements and radionuclides from inactive mining areas to off-site locations in New Mexico and Wyoming. These areas were selected because extensive uranium mining has occurred to date and is likely to continue. Since the mid 1950's, these States have produced the majority of domestic U_3O_8.

Samples of surface soils, stream sediments, mine drainage water, and surface water were collected. Interpretation of the data is complex since wind and water erosion work together at different seasons of the year to transport the mine material stored above ground. Compounding the problem is the semiarid environment of Wyoming and New Mexico where precipitation averages 13 to 31 centimeters per year and occurs primarily in the spring. The short-duration "flash flood" summer thundershower will move large quantities of material in increments rather than a gradual erosional pattern.

Sampling was conducted during April and May 1979 at a site within the South Powder River Basin in Wyoming, at two sites in Poison Canyon drainage, and at the San Mateo mine areas in New Mexico. Most of the soil samples were obtained in well-defined runoff gullies where mine and mine spoil drainage intersected stream beds. The arid nature of the locations did not provide much opportunity to observe and to measure surface runoff characteristics.

Sampling locations at the Morton Ranch property in Wyoming are summarized in Fig. G.19. The types of samples are identified in the legend. Samples taken at the San Mateo mine in New Mexico are depicted in Fig. G.20.

At three locations at Morton Ranch, a 75 cm profile was taken which consisted of 15 consecutive 5 cm segments. The potential variability of trace metals and radionuclides at depth may be related to the solubility of the species and the amount of surface water residence time. Understanding the fractionation of surface contaminants in the soil column is important in evaluating the transport of various species by redissolution or leaching.

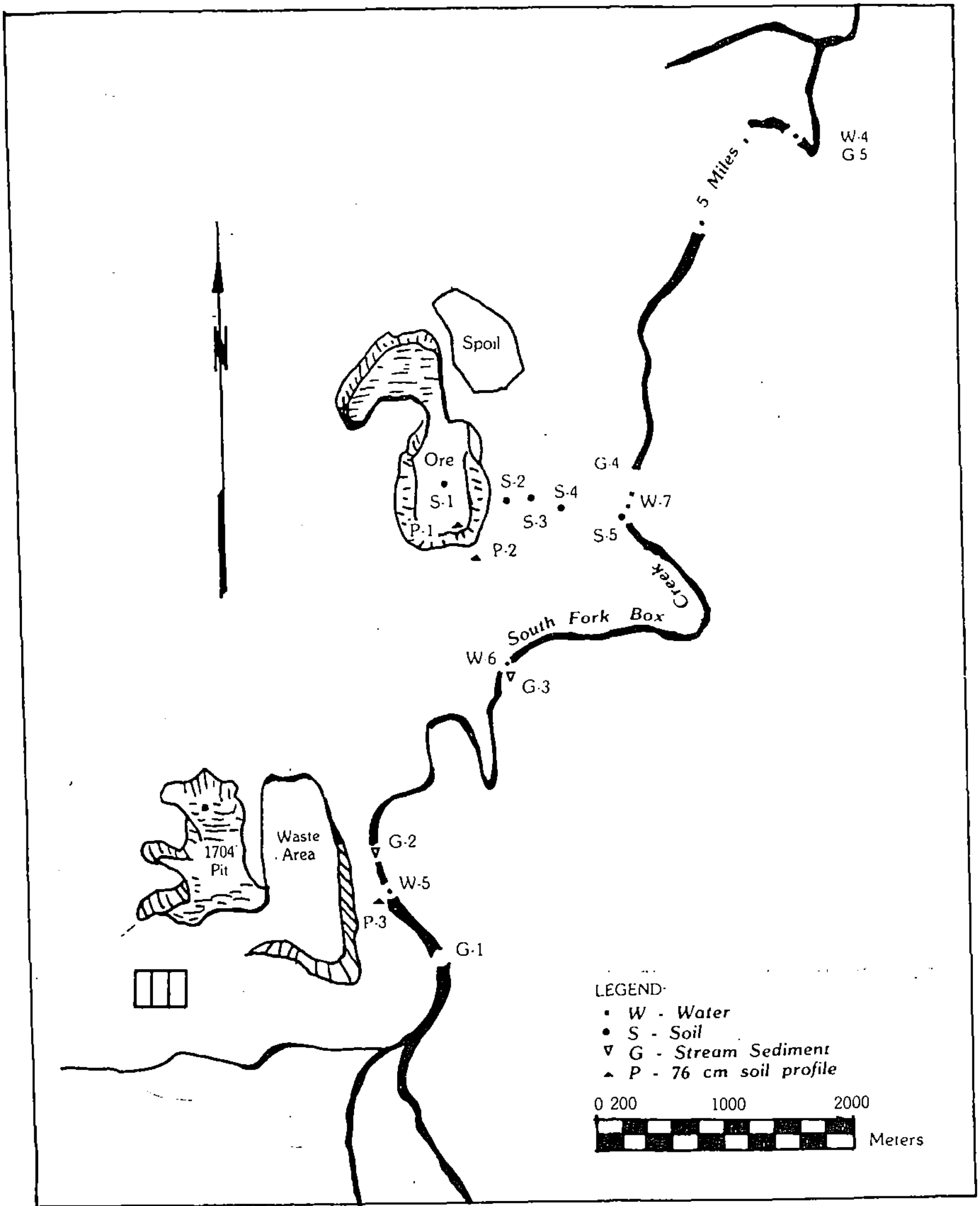


Figure G.19 Location of sampling sites at the Morton Ranch mine. South Powder River Basin. Wyoming

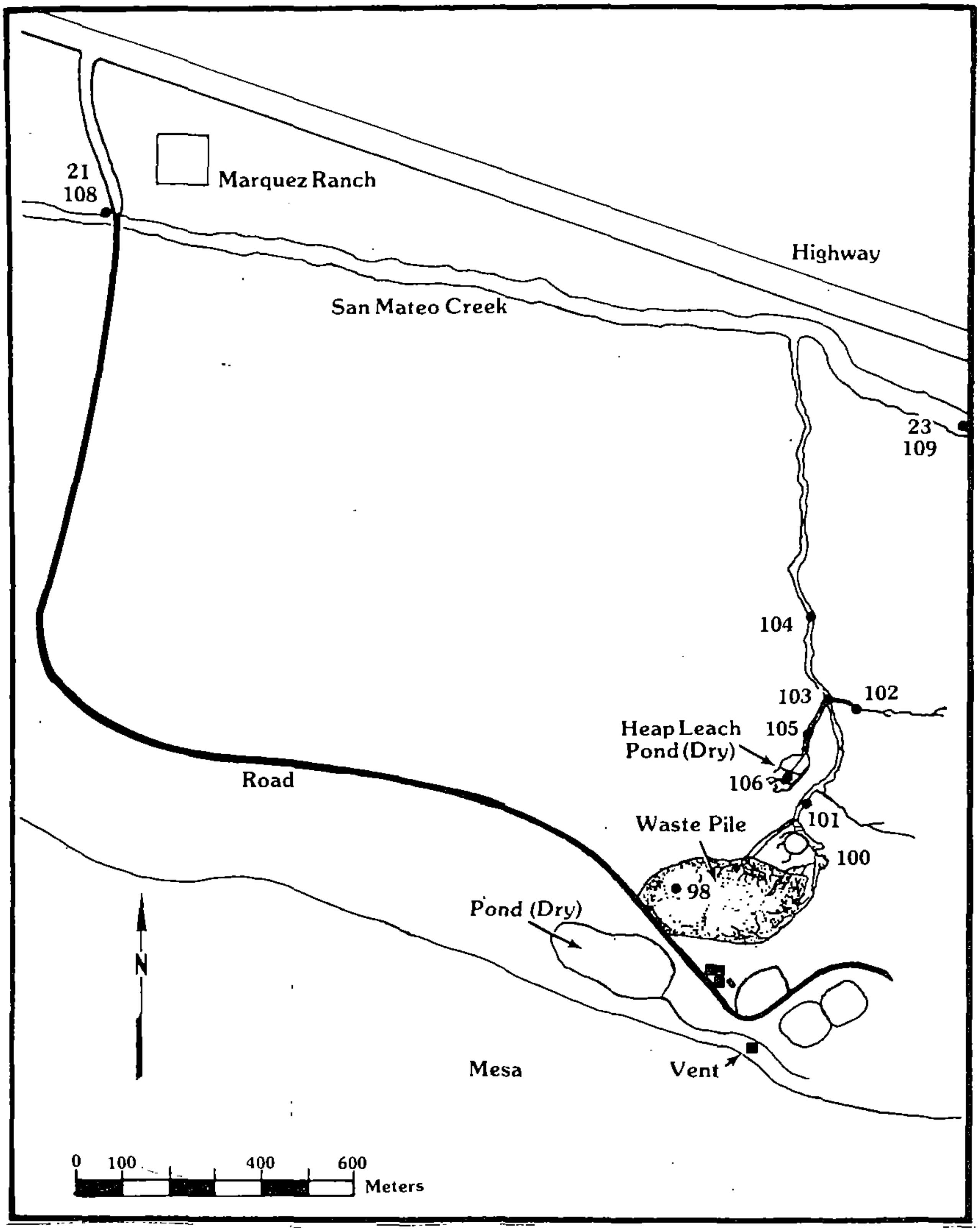


Figure G.20 Sample locations for radionuclides and select trace metals in sediments, San Mateo Mine, New Mexico

G.2.2 Discussion of Results

The radiochemical and trace metal analyses for the stations shown in Fig. G.19 are contained in Tables G.4, G.5, G.6, and G.7 (Written Communication from N.A. Wogman, Battelle Pacific Northwest Laboratory, 1979).

Table G.4 Trace elements and radionuclides in water in the South Fork of Box Creek drainage at UNC Morton Ranch lease

Location[a]	pCi/ℓ		μg/ℓ			
	Ra-226	U-238	Ba	Se	V	Mn
W-3 H_2O	15.5	1220	63	334	8	77
Filter	18.7	33.7	22	38	47	22
W-5 H_2O	4.2	287	76	78	5	9
Filter	4.48	2.97	16	0.6	8.1	29
W-6 H_2O	0.6	34.2	11	< 4	10	91
Filter	0.091	0.209	< 4	< .1	< .6	11
W-7 H_2O	0.5	38.7	86	< 4	7	22
Filter	0.18	0.976	4	< .1	1.0	18
W-4 H_2O	0.13	10.9	44	< 4	6	149
Filter	0.045	0.188	< 3	< .1	1.7	6.7
Acid Blank H_2O	N.D.	N.D.	1	< 4	< 5	< 3
Filter	0.59	0.073	< 3	< .12	< .4	< .2

[a] See Figure G.19.

Note. -- United Nuclear Corporation (UNC) has recently transferred its interest to the Tennessee Valley Authority.

Table G.5 Radionuclides and trace metals in sediments in the South Fork of Box Creek at UNC Morton Ranch lease

Location[a]	pCi/g		µg/g				
	Ra-226	U-238	Ba	Se	V	Mn	As
G-1	1.3	0.41	750	<1	<39	70	< 1.6
G-2	1.8	1.04	690	<1	<42	114	2.9
G-3	6.8	7.46	550	7	90	3390	10
G-4	1.4	1.45	750	<1	<51	100	<1.7
G-5	1.2	0.87	720	<1	<50	107	3.4

(a) See Figure G.19.

The results in Tables G.4 through G.7 may indicate dispersal patterns of mine drainage and waste in a semiarid environment. Intermittent runoff from surface or underground mining spoils or an irregular low-volume discharge of mine water compounds the difficulty in attributing the impacts to either suspended or dissolved species. The analyses performed on samples from the South Fork of Box Creek cannot be used to describe typical impacts from larger operations; yet the complexity of stream sedimentation and dilution is evident and can signal precautions in monitoring any site of mining operation.

For instance, water samples collected from Box Creek represent an intermittently flowing stream without a constant mine discharge. Even in spring after most of the snow has melted and recharged the upper reaches, streams such as Box Creek do not flow but rather contain shallow impoundments. There seems to be a movement of water beneath the stream sediments which supports these impoundments without observable surface flow. Each of the water and sediment samples was from impoundments, except for sediment sample G-1 which was from a dry stream bed. The results in Table G.4 show that radium-226 and uranium-238 in solution decrease in concentration with downstream distance. Station W-3 is hydrologically separate from the drainage basin at the present time, but represents mine discharge when dewatering begins.

Table G.6 Radionuclides and trace metals in soils near the 1601 open pit mine, UNC Morton Ranch lease, Wyoming

Location[a]	pCi/g			μg/g					
	Ra-226	U-238	Th-230	Ba	Mn	V	Zn	Se	As
S-1	119	188	161	760	205	110	29	17	7.5
S-2	33	7.21	38.6	800	250	160	85	25	11
S-3	3.8	1.87	3.71	760	200	70	36	<1	6.8
S-4	1.9	1.78	3.54	530	190	100	58	<1	6.0
S-5	2.5	1.64	1.91	810	140	<50	27	<1	4.2
S-6[b]	1.86	1.62	1.74	680	180	100	33	<1	3.9
S-7	3.4	1.60	2.71	570	180	70	32	<1	5.6

(a) See Figure G.19.
(b) Background sample.

In conjunction with the decreasing soluble species with distance downstream, there is a possible trend of increased levels in sediments (see Table G.5). This may be, in part, due to the sampling locations (ponded water). It is possible that the soluble species precipitate in standing water either because of evaporation increasing the solute concentration or the increase in pH. The pH of the 1704 mine water increased from 5.2 to 7.2 eight km downstream in Box Creek. Another possibility is that these ponds receive surface runoff from several hundred meters of stream bed and, therefore, have higher sediment loading.

The data in Table G.6 are from a series of soil samples obtained from the natural drainage leading from the inactive 1601 open pit to the South Fork of Box Creek. This mine is dry and therefore it has no liquid discharge to Box Creek. Over 1,100 m separate the mine spoils material from the creek bank. The soil samples were collected at 183, 366, 567, and 1,100 m from the spoils bank. If there had been runoff from cloudbursts or snow melt, sheet erosion across this plane could move the spoils material to the creek. This mine was operated for a very short time eight years ago; therefore, the full impact of the long-term erosion could not be measured. Also, wind erosion complicates the predictive value of these results since this channel is aligned with the predominant wind direction.

Table G.7 Radionuclides and trace metals in soil profiles at the open pit mines, UNC Morton Ranch lease, Wyoming

Location[a]	Depth (cm)	pCi/g			µg/g			
		U-238	Ra-226	Th-230	Mn	Se	Ba	V
P-1	0-2	188	119	161	205	17	760	110
	4-6	1.62	2.8	1.79	120	1.2	720	< 50
	10-12	2.12	1.8	1.87	59	< 1	470	150
	22-24	1.21	1.4	1.0	86	1.9	550	130
	28-30	1.26	1.5	1.16	57	< 1	590	70
P-2	0-2	11.0	33.2	31.4	130	2.7	690	90
	4-6	5.39	13.0	18.0	94	1.1	760	< 50
	10-12	1.57	2.6	2.15	130	< 1	770	60
	22-24	11.0	146	238	190	1.3	560	120
	28-30	5.73	485	481	72	< 1	730	90
P-3	0-2	3.3	8.2	5.5	120	1.3	701	130
	4-6	3.0	52.0	11.1	110	1.1	693	70
	10-12	2.69	1.86	1.35	210	1.4	591	130
	22-24	1.97	1.62	1.78	270	1.1	618	90
	28-30	3.51	2.1	1.5	350	1.1	660	70

[a] See Figure G.19

The trend of decreasing radioactive species with increasing distance from the spoils bank is evident. The background results for S-6 are composite samples of at least six locations where the gamma survey indicated no surface contamination. The results show that Ra-226, U-238, and Th-230 are measurable and decreasing towards the creek. These concentrations above the background samples can be attributed either to wind or water erosion from the 1601 spoils bank.

Water erosion of the mine waste pile is documented by the gullying scars on the sloped surfaces. Data in Table G.6 indicate definite migration of this material at least 360 m from the largest gully. Yet it is possible that this contamination may have occurred while the mine was active. The ore body is sandstone, the fines of which could be resuspended by vehicle traffic or equipment operation.

In Fig. G.20 the drainage pattern for the San Mateo mine in New Mexico is depicted. As in the case of the 1601 mine in Wyoming, nearby drainage courses are dry most of the year. Runoff in San Mateo Creek lasts for several months as a result of snow melt, and is nil the rest of the year, except for brief runoff from storms. Radium-226 data for the sediments (see Table G.8) reflect decreasing concentration with distance to San Mateo Creek, especially within 350 to 460 m from the waste pile. The radium in San Mateo Creek downstream from the intersection of the mine drainage is higher than the gully data would indicate. Data for sample 104 seem to indicate that contamination has not moved from the gully wash to the creek beds, but this is considered most unlikely on the basis of known erosion and obvious topographic relations.

Barium and selenium trends, for the most part, follow a similar pattern of decreasing concentration with distance from the waste pile. Arsenic concentrations are an exception. Sediments show increasing arsenic to 350 to 460 m downstream and then decrease from that point to San Mateo Creek. In the creek sediments, arsenic and barium concentrations are higher than would be expected if mine wastes were the sole source of these elements.

Sediment and water samples (Tables G.8 and G.9, respectively) from San Mateo Creek indicate that barium and manganese concentrations are either equal to or higher upstream of the gulley intersection than below it. This apparent anomaly and the higher-than-expected concentrations for radium and arsenic in sediments cannot be readily explained.

In summary, the data collected during April and May 1979 at the San Mateo mine do not indicate that mine waste has reached San Mateo Creek; yet downstream sediments show anomalies for certain elements. The transport of mine waste is measurable approximately 370 to 460 meters from the waste pile.

Water erosion is the likely reason for the contamination, but wind may also be dispersing material. Meteorological data, particularly wind roses, are unavailable at this time.

Table G.8 Radionuclides and trace metals in sediments from the drainage of the San Mateo mine and from San Mateo Creek, New Mexico

Location[a]	pCi/g		μg/g					Remarks
	Ra-226	Th-232	Ba	Se	V	Mn	As	
98	117	0.86	-	-	-	-	-	Waste pile
100	55	0.64	566	3.9	78	176	3.1	Base of pile
101	36	0.66	484	3.7	114	179	5.1	100 m from pile
103	1.6	0.43	383	1.2	<50	191	6.2	400-500 m from pile
104	0.77	0.54	434	<1	<42	146	3.6	600-700 m from pile
105	1.2	0.80	517	<1	<52	186	3.8	Heap leach pile
102	0.77	0.55	562	1.2	102	473	5.5	Background
109	0.38	0.39	695	<1	<51	152	2.2	2 km upstream
108	8.1	0.53	597	<1	55	157	5.2	Downstream

[a] See Figure G.20.

Table G.9 Radium-226 and trace elements in water from San Mateo Creek near San Mateo mine discharge point

Location[a]	pCi/ℓ,	μg/ℓ						
	Ra-226	Ba	Se	V	Mn	As	Mo	Zn
23 (upstream)	---	79	< 4	8	55	9	23	56
21 (downstream)	12.5	26	21	21	10	9	170	150

[a] See Figure G.20.

Data from three soil profiles near the spoils areas of the 1601 and 1704 mines at Morton Ranch were used to investigate possible downward migration of soluble species. In semiarid environments, small precipitation events usually result in little noticeable runoff. In many areas, the surface soil is very porous and rain immediately infiltrates. The disturbed spoils material is probably of even higher porosity; therefore, soluble species could, over a period of time, begin to migrate to greater depths. Based upon solubility and frequency of rewetting, a fractionation of species could occur.

The overburden at 1601 and 1704 mines contains a high percentage of clay. The resultant spoils bank is a homogeneous mixture of clay and sandstone. It was observed during the collection of the soil samples that the clay was moist, highly plastic, and obviously of low permeability. Very slow downward migration of surface water would be expected; consequently, not much fractionation of the species would result.

The results in Table G.7, however, show contradictory evidence of isotopic disequilibrium. The isotopes of uranium, radium, and thorium are near equilibrium conditions throughout the profile P-1 taken above the slope of the 1601 spoils bank. However, the lower layers of profile P-2 show a marked departure of uranium from the radium and thorium. Since uranium is more soluble than the other species, it is difficult to explain the anomaly.

In profile number 1, the top segment probably contains ore material eroded to the spoil surface. The segments at greater depth show species equal to or less than the data reported as background on the surface in Table G.6 (S-6). This would imply that no downward migration had occurred on the surface of the spoils area. Note that the clay-like matrix of the spoils may have prevented much surface infiltration, which accounts for the shallow erosional scars on horizontal surfaces.

Profile number 2 was obtained in an alluvial fan below the spoil bank slope. The data suggest that the profile did not extend below the alluvium and into the spoil material. The anomaly at greater depth cannot be explained, but, perhaps, irregular wind and water erosion of the spoils material caused this layering effect. Still, the isotopic disequilibrium is not explained.

Profile number 3 was a saturated clay column which contained, from the odor, a percentage of organic material that was undergoing bacterial decomposition. Sheep in the area use the pond nearby and this may account for the source of the organics. The results for profile 3, again, show little above background concentrations at greater depth, except for slight increases in manganese, selenium, and uranium. The profile was in the sediments of Box Creek close to the runoff observed from the 1704 spoils bank. The radium and uranium data show that concentrations in sediments in the first 30 cm are higher than what was observed further downstream at point G-2 (Table G.5). This is undoubtedly the result of erosion from the spoils bank. This clay sediment matrix could be subject to transport further down Box Creek but only under high flow conditions.

G.2.3 Conclusions

In summary, the field studies attempted to identify and quantify the transport of mine spoils material. There is evidence that contamination is measurable up to 370 to 460 m in a gully draining the San Mateo pile and, perhaps, 570 m in the natural sloping plane in which the 1601 Morton Ranch mine waste is located. The mechanism of transport is complex because of the semiarid environments. There is a good chance of wind and water erosion combining to move spoils material these distances in under 10 years.

The data also support the conclusion that it is not evident that radionuclides or trace metal species have reached intermittent streams, either as soluble or particulate material. Anomalies were uncovered in San Mateo creek which cannot be explained from the samples collected so far. The water and sediment samples in the South Fork of Box Creek show decreasing concentrations of radium and uranium isotopes with downstream distance, but not so clearly for the trace metals. The levels of radium and uranium are not conclusive of major off-site movement of the spoils material.

The soil profiles obtained at the Morton Ranch leasehold do not support the conjecture of downward migration. Perhaps the clay-like consistency of the spoils material allows for too little fractionation after only eight years. The isotopic ratio discrepancy at greater depth in the profile of an alluvial fan of spoils is not understood at this time.

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